RHIC upgrades for heavy ions and polarized protons

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Abstract. The Relativistic Heavy Ion Collider (RHIC), in operation since 2000, has exceeded its design parameters. The Enhanced Design parameters, expected to be reached in 2008, call for a 4-fold increase over the heavy ion design luminosity, and a 15-fold increase over the proton design luminosity, the latter with an average polarization of 70%. In 2009, it is planned to commission a new Electron Beam Ion Source, offering increased reliability and ion species that cannot be supplied currently. The upgrade to RHIC II, based on electron cooling of the beams, aims to increase the average heavy ion luminosity by an order of magnitude, and the polarized proton luminosity by a factor 2-5. Plans for an electron-ion collider eRHIC are covered in another article in these proceedings.

Keywords: Heavy ions, Polarized protons, Collider
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INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory was commissioned in 2000. It is currently the only collider of heavy ions, and the only collider of polarized protons. Since 2000 the heavy ion luminosity has increased by 2 orders of magnitude (Fig. 1), and now exceeds the design values (Tab. 1). Four different ion combinations collided (Au^{79+} on Au^{79+}, d^+ on Au^{79+}, Cu^{29+} on Cu^{29+}, and polarized p^+ on polarized p^+), including one asymmetric combination, at a total of 8 different center-of-mass energies (from 19.6 GeV/n to 409.8 GeV). The average polarization of stored proton beams reached 46%, and allowed for the first long physics run in 2005. Proton beams can be delivered with transverse and longitudinal polarization. In the most recent polarized proton run, 56% of the calendar time was spent in physics stores. Luminosity was delivered to 2 high-luminosity experiments (PHENIX and STAR), and three more experiments (BRAHMS, PHOBOS, and PP2PP).

The planned RHIC upgrades target higher luminosity and proton polarization, as well as increased operational flexibility and reliability. Here we will discuss the evolution towards the Enhanced Design parameters, the new Electron Beam Ion Source (EBIS), and RHIC II, a luminosity upgrade based on electron cooling. A number of other upgrades are planned or under investigation. These include reliability replacements in the more than 40-year old injector complex; emittance reduction measures in the injector chain; stochastic cooling in RHIC [1]; the extension of the energy range to higher [2] and lower values; an upgrade of the polarized source [3], a second cold snake in the AGS, a further reduction of the beam size at the interaction point, and the use of electron lenses and superbunches [4]. In this article we will not report on the planned electron-ion collider eRHIC. This is covered in a separate article [5].

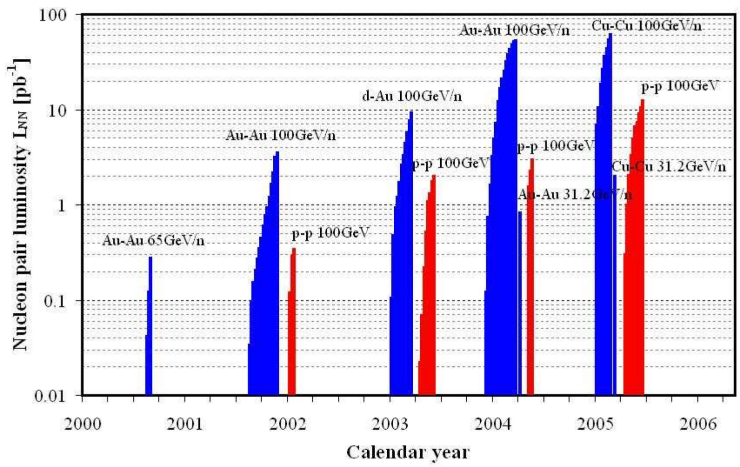

FIGURE 1. Integrated nucleon-pair luminosity delivered to PHENIX, one of the high-luminosity experiments at RHIC [6]. The integrated nucleon-pair luminosity is defined as $L_{NN} = \int A_1 A_2 \mathscr{L} dt$, where $\mathscr{L}$ is the luminosity, and A_1 and A_2 are the number of nucleons of the ions in the 2 beams respectively.

ENHANCED LUMINOSITY AND POLARIZATION

The enhanced design parameters call for an increase in the heavy ion luminosity by a factor 2, and an increase in the polarized proton luminosity by an order of magnitude (Tab. 1). In addition, the average proton polarization in RHIC stores is to increase from 46% to 70%. Those goals are expected to be reached in 2008.

The intensity of all beams is limited by dynamic pressure rises, caused by electron clouds. In the warm sections, the beam pipes are replaced by NEG coated pipes, which have a lower Secondary Electron Yield, and act as a distributed pump when activated. In the cold sections, additional pumps were installed to evacuate the beam pipe to a lower pressure before the cool-down of the magnets.

The proton polarization and bunch intensity is currently limited by the AGS, which is the injector for RHIC. It is expected that both limits can be overcome when a cold Siberian snake, installed in 2005, is fully commissioned. The luminosity lifetime for protons is dominated by the beam-beam interaction, and a number of improvements are planned to ameliorate the effect.

ELECTRON BEAM ION SOURCE

Currently only species for which high intensity negative ion sources exist can be used. These negative ions are accelerated in the electrostatic Tandem accelerator, and then injected into the AGS Booster. It is planned to replace the pair of Tandems with an Electron Beam Ion Source (EBIS) followed by a Radio Frequency Quadrupole (RFQ) and short Linac [7]. With the construction of EBIS a further upgrade of the Tandems can be avoided, needed to maintain their reliability, and new ion species can be prepared for RHIC, including uranium and polarized ^{3}He. The overall system reliability is expected to be improved at reduced operating costs, with beam intensity and brightness comparable to the existing scheme. It is planned to commission EBIS in 2009.

TABLE 1. Main RHIC parameters for gold ions and polarize protons.

Quantity	Unit	Design 1999	Achieved 2005	Enhanced Design 2008	RHIC II $\geq$2012
Au^{79+} on Au^{79+}					
Beam energy	GeV/n		— 100 —		
Number of bunches	...	60	45	— 112 —	
Bunch population, initial	10^9	1.0	1.1	— 1.0 —	
β-function at IP	m	2.0	1.0	1.0	0.5
Peak luminosity	10^{26}cm^{-2}s^{-1}	12	15	32	90
Average store luminosity	10^{26}cm^{-2}s^{-1}	2	5	8	70
polarized p^+ on polarized p^+					
Beam energy	GeV	250	100	— 250 —	
Number of bunches	...	60	106	— 112 —	
Bunch population, initial	10^{11}	1.0	0.9	— 2.0 —	
β-function at IP	m	2.0	1.0	1.0	0.5
Peak luminosity	10^{30}cm^{-2}s^{-1}	15	10	220	750
Average store luminosity	10^{30}cm^{-2}s^{-1}	10	7	150	500
Average store polarization	%	–	46	70	70

ELECTRON COOLING – RHIC II

The luminosity lifetime of heavy ion beams is dominated by intrabeam scattering effects. These lead to particle loss out of the radio frequency buckets, and to an increase in the beam size during stores. The effects of intrabeam scattering can only be overcome through active cooling. To cool heavy ion beams at store, an electron beam of 54 MeV with a charge of 5 nC per bunch is required. Such an electron beam has a power of 2.5 MW. A high intensity, high brightness superconducting rf electron gun is being developed, which will injected into a superconducting energy recovery linac (ERL). To advance the technology, a R&D ERL is being constructed, in which the electron beam will reach about half the energy required in the electron cooler. Technically constrained, electron cooling could be commissioned in RHIC in 2012.

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REFERENCES

1. J.M. Brennan and M. Blaskiewicz, COOL05, to be published as AIP conference proceedings (2005).
2. W.W. MacKay et al., proceedings of the 2001 Particle Accelerator Conference, pp. 3129-3131 (2001).
3. A. Zelenski, private communication (2005).
4. W. Fischer and M. Blaskiewicz, AIP Conference Proceedings 693, pp. 244-247 (2003).
5. V. Ptitsyn, these proceedings; R. Fatemi, these proceedings.
6. W. Fischer, http://www.rhichome.bnl.gov/RHIC/Runs/ (2005).
7. J. Alessi et al., proceedings of the 2005 Particle Accelerator Conference, pp. 363-365 (2005).
8. I. Ben-Zvi et al., proceedings of the 2005 Particle Accelerator Conference, pp. 48-51 (2005).